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The impact of environmental noise generated from ports: outcome of MESP project

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Abstract: Ports are characterized by several complex operations. Accordingly, the analysis of noise results is complicated due to the presence in the same area of diverse sound from ships, trade and also from industrial and shipyards activities as well as auxiliary services producing negative effects on natural ecosystem and the urban population. The ENPI CBC MED project Managing the Environmental Sustainability of Ports for a durable development (MESP) addressed the pollution reduction from port activities through the implementation of a multidisciplinary approach in air, noise and water sectors, encompassing technological, regulatory and administrative solutions to ensure natural and urban sustainability and high level of life quality in surrounding territories. To prevent a heterogeneous development, the "status quo" of ports in Northern and Southern Shores of the Mediterranean Sea was analyzed and a guideline on methodologies, good practices and measurement assessment, adaptable and transferable in different port contexts was elaborated. To assess the procedures, validation tests have been carried out to different real cases. In noise sector pilot projects in the ports of Patras, Greece, and Tripoli, Lebanon, have been implemented. Due to the dissimilar scenarios, in terms of orography, facilities and activities, different noise mitigation actions and interventions were consequently accomplished.

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1 Introduction

Port infrastructures, particularly in Mediterranean area territories, are often an integral part of coast-cities, deeply merged in the urban texture. Port facilities and activities carried out within harbour boundaries often represent an opportunity for the local economy, but if not well planned and managed they can also represent a health threat for citizens living in the surrounding area. In fact, an improper and unsustainable management and development of ports usually mean difficult relationships with urban areas in terms of land use, pollution and citizens' quality of life [1].

Harbours contain several noise sources in various sectors with different characteristics. Sources include ferries, ships and trade operations, industrial and shipyards as well auxiliary services [2]. Such activities strongly impact the environment of the surrounding area and, as a consequence, local population, port workers and tourists as well as both terrestrial and marine ecosystems.

The European Sea Port Organization (ESPO), after the PPRISM (Port PeRformance Indicators: Selection and Measurement) project [3], delivered the first European Port Performance Dashboard in 2012. In 2013, ESPO produced the second edition of the Port Performance Dashboard [4], which presents the environmental priorities of the sector from 1996 to 2013. Noise impact reaches and maintains a high ranking from 2004.

Noise pollution is proven to produce negative impacts both on the natural eco-system and the urban population (harming human health [5], *e.g.* causing hearing and cardiovascular disturbances, high blood pressure, sleep disturbances, reduction in efficiency, annoyance, mental stress, lack of concentration). The World Health Organization (WHO) in its "Burden of disease from environmental noise" [6] underlines that unlike other environmental stressors, noise exposure is increasing in Europe. Studies on port noise exposure of resident population [7] and noise impact of ports are relatively rare (see *e.g.* [8–11]) and are quite concentrated in the last few years; a brief review on the topic can be found in [12].

The EU Environmental Noise Directive (2002/49/EC) [13], provides a basis for measures development aimed to reduce noise emitted by the major sources, and considers ports as industrial activities. Recent studies and surveys (*e.g.* [14–17] and even a specific session "Port and noise" held at the Euronoise 2009 [18–30]) underlined that port infrastructures present highly complex situations, and no specific regulations addressed to noise control and management within harbour areas exist.

In particular, the noise generated by ships has an impact inside and outside the ship itself on both crew workers, passengers as well as the surrounding areas. The assessment of the impact is currently difficult due to the lack of specific standard instruments and indicators able to characterize and control the ship noise type [31–35]. Different approaches have been investigated in literature to evaluate ships sound power levels, considering ships both as mobile (ship under way) or stationary sources (ship berthed at wharf) [36–44], but a common method is still lacking.

To avoid important environmental and social-economic impacts, it is necessary to take immediate actions, involving the most experienced European and international professionals, local authorities, port managers and research entities.

According to the general objectives of the ENPI CBC MED (European Neighbourhood and Partnership Instrument Cross-Border Cooperation in the MEDiterranean) Programme, MESP project (Managing the Environmental Sustainability of Ports for a durable development) aims to decrease pollution levels concerning air, noise and water deriving from port activities and provide citizens, tourists and workers a healthier and usable environment [45]. This can be possible through 1) procedures and tools that allow the objective valuation of the sustainability of ports and 2) the creation of practices and procedures easily applicable on both sides of the Mediterranean Sea.

The MESP project target goals include the identification of best practice and procedures and the realization of pilot projects in different port in order to firstly assess the validation of the selected methodologies. In this way, these actions can help management authorities and port areas and infrastructure users in reaching a higher level of sustainability and in decreasing the pollution levels.

In this paper a specific focus on the noise sector developed within MESP project activities is described.

2 MESP project

Mediterranean ports currently represent the main door of access to enter Europe and the Middle-East territories for transports from all over the world. The sea and land traffic flows, both in terms of goods and passengers, are increasing due to the intensification of maritime traffic producing critical situation both within the harbour boundaries and on the urban neighbourhoods.

Ports present highly complex scenarios, encompassing a wide variety of activities linked directly with the harbour tasks, such as cargo and passenger transport, merchandise handling to and from the harbour, large ships powering, sludge and sewage, goods handling, and others indirectly related, *e.g.* heavy or light vehicle and railway traffic, waste production, power plants.

It is well known that all these activities are relevant sources of pollution with a strong impact on the environment of the surrounding area [8] and, consequently, local population, port workers and tourists as well as both terrestrial and marine ecosystems. Therefore, the protection of the environment and the prevention of pollution scenarios is an important competitive feature for the whole Mediterranean basin. In fact, the intensification of maritime traffic, both in terms of goods and passengers, needs to be accompanied by an environmentally sustainable management of port areas aimed at reducing unsafe consequences for local populations.

According to the general objectives of the ENPI CBC MED Programme, MESP project (Managing the Environmental Sustainability of Ports for a durable development, Grant Agreement contract number 10/2263) aims to reduce air, noise and water pollution due to port activities, ensuring environmental sustainability of harbour activities and a high level of life quality in surrounding territories.

The MESP project, started in June 2012 and having a duration of 42 months, is developed by six partners from four countries both from the Northern and Southern part of the Mediterranean basin: Italy, Greece, Lebanon and Jordan (Fig. 1). The partnership is composed of: the Mechanical Engineering Department (DIME) of the University of Genoa, Italy (as the Beneficiary); the Physical Oceanography Marine Science Station (MSS) from the University of Jordan, Aqaba, Jordan; the Port Authority of La Spezia, Italy; the Al-Manar University of Tripoli (MUT), Lebanon; the Department of Environment and Sustainable Development from the Patras Municipal Enterprise for Planning & Development S.A. (ADEP), Greece and the Exploitation Office of Port of Tripoli (OEPT), Lebanon.

Figure 1: Distribution of MESP partners in the Mediterranean basin.

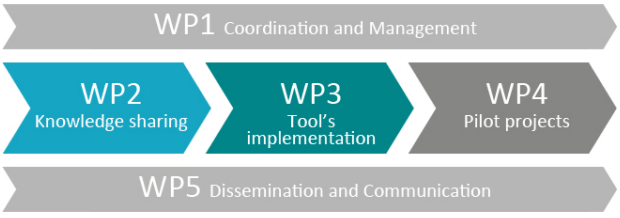

Figure 2: Schematic overview of MESP Work Packages.

To achieve the aforementioned targets, MESP aims, through a multidisciplinary approach, to identify the best practices and procedures useful to define common strategies applicable in different territorial and local realities throughout the Mediterranean area. This not only allows reaching higher sustainability and decreased pollution levels giving back to citizens, tourists and workers a healthier and usable environment, but also aims to help in preventing a heterogeneous development of port infrastructures in the Mediterranean basin and enable the entry of new methodologies which can facilitate work activities and environmental pollution abatement actions.

To assess all the procedures, validation tests are performed through the application of the selected methodologies to different real cases. For any sector two different ports for demo intervention have been chosen. To have an overall overview of improvements, pilot interventions on all the three sectors (air, noise and water) are implemented in the Port of Tripoli, as well as in Patras for noise sector, in La Spezia for air and in Aqaba for water.

3 The project activities

MESP activities have been articulated in five Working Packages (WPs) as shown in Fig. 2. Besides the transversal WP1 on Coordination and Management and WP5 on Dissemination and Communication, WP2 (Knowledge sharing), WP3 (Tool's implementation) and WP4 (Pilot projects) represent the project core. Through these activities, a scientific development has been then implemented to reach results and output that can be applied to different local realities.

The WP2 "Knowledge sharing" considers the state of the art at an international level and in the partners' respective countries on the air, water and noise pollution evaluated from different points of view such as that of legislation, management tools, technologies, and the most significant international experiences in the matter of study.

The analysis of already-tested methodologies and procedures has been a base for the MESP activities as a guarantee of the developed efficacy and the quality of practices. The gathered documents have been then transferred and shared among the partnership as a reciprocal exchange of information to create a common and homogenous base as a starting point for the conception of a single management tool for the pollution abatement in ports.

The WP3 "Tool's implementation" represents a very important phase of the project, in as much as the collected information and the exchange of knowledge among several partners and the methodologies, technologies and practices outlined in WP2 represent the basis for the definition of a specific methodological approach for the sustainable management of ports.

In this way, to define the starting point for the build-up of the final guidelines, a detailed study on real port situations and surrounding urban context appeared to be significant. Accordingly, specific analysis of the four MESP ports territorial areas (Aqaba, La Spezia, Tripoli and Patras) have been conducted, collecting information particularly on trade, logistics, transport, mobility and future territorial planning.

Once the prescriptions towards a port sustainable management have been defined and developed into the Guidelines Document, the validation of the identified tools applicability and transferability have been carried on with the application of formulated criteria to several real scenarios through demonstrative actions: in this way, the interventions carried out in WP4 represents the project result, as a guarantee of project proposals and theoretical considerations of previous steps (WP2 and WP3).

4 MESP results

As previously mentioned, MESP expected results in pollution abatement are different in nature, facing the improvement of the life quality of population (and port users) and safeguarding of the natural environment. MESP partners targeted to achieve the reproducibility of outputs and results throughout the Mediterranean basin and the homogenization of procedures, methodologies and approaches in the basin to simplify the application of selected methodologies and tools and, in this way, to increase cooperation actions. This can only be possible through the building of a strong cooperation network and the creation of long-lasting collaborations among different institutions such as harbour cities, port authorities and universities.

The MESP project has been able to promote the environmental sustainability at the basin level, thanks to a partnership composed of key actors in the field of environmental protection with a high level of heterogeneous expertise on pollution phenomena. It has shown itself capable of enriching the state of the art with experience of different port context, from the perspective of cultural, orographic and harbour activities. The choice of MESP members was strongly connected to partner skills and experiences in environmental pollution thematic. Each partner had deep knowledge on issues on their own port reality. Some partners brought a particular contribution, especially within the awareness of the port context and the different related activities. During the several phases of the project, the different partners worked on the several activities offering their experience and support.

Facing issues related to the proper fruition of the territory by the citizens, one of the most important results achieved by MESP is improving the usability of ports areas by population and tourists. Besides recommendations, actions and technologies implemented to limit the spread of pollution from port area, the key element for their executing is a strong relationship with the local authorities and stakeholders. The presence of territorial managements and public administrations of the involved countries is extremely important to increase the environmental awareness and collect local information on organization, administration, and competences, as a first step. Through detailed knowledge of territory, a correlation of environmental problems is allowed with the directly and indirectly involved activities in the port, ensuring the local support to the implementation of the project and suggesting possible methodologies, technologies and alternative practices, presenting their own successful experiences in the field and giving their own opinion around project outcomes and results (as in the case of the Lebanese and Jordan Associate partners, the Urban Community of Al Fayhaa and the Jordan Environment Society).

In order to stimulate and increase capacities both of the public authorities competent for the port areas and the infrastructure management and their users, MESP partnership developed specific guidelines containing tools, methodologies and approach applications to be applied in harbours and ports. It follows, then, that one of the main results in the MESP project was the formulation of common tools for procedures and tools facilitating the improvement of port sustainability through appropriate approaches and procedures. From the result of such analysis, the document "Roadmap on Sustainability Criteria: Guidelines for Port Environmental Management" have been then redacted as a roadmap on methodologies, good practices

Figure 3: Cover of the "Roadmap on Sustainability Criteria: Guidelines for Port Environmental Management" document.

and measurements assessment for the environmental sustainability of Mediterranean harbour areas (Fig. 3).

In compiling the document, specific cross-cutting criteria have been chosen by the partnership to approach the environmental and sustainable improvement and management suitable for all ports areas. In fact, beyond the peculiarities of the different pollution fields, there are actually some essential key concepts at the basis of the procedures in common among all, such as simple attitude, methodologies and indicators to have a general scenario, correct identification of the laws and standard to be followed and interference with port activities normal operation. These criteria, indeed, relate to the general approach to the pollution issue and can be applied a priori to any port context. After this step, a deeper analysis of the criteria selected in the previous actions has been carried out. Through this action the most suitable methodologies, approaches and tools, finalized to the reduction of environmental impacts, have been identified and implemented by the different scientific competences. Their implementation aims to reach the target goal of the outcomes reproducibility and the consequent replication in the different Mediterranean ports background. The methodologies chosen within the activities has been addressed to the methods, skills and processes and to the approach to pollution problems by following the procedure outlined in Fig. 4.

Figure 4: Representation of pollution issues approach.

After an overview of the general approach to pollution reduction, a specific element must be focused on the analysis of different aspects such as the definition of the most significant indicators to be considered and evaluated and the basic measurement equipment to use to perform a proper measurement campaign, the technical standard and procedures of measurement to be followed, the measurement methodologies to adopt for the pollution sources identification, the individuation of the most critical sources and reports template for the correct collection of information and the measuring data.

To contrast the poor knowledge about existing technology and procedures applied outside each partner territorial contest, preventing an homogeneous development of port infrastructures in the Mediterranean basin and, above all, hampering the entry of new methodology and technologies which can absolve works with a large savings of energy and a substantial environmental pollution abatement, the MESP partnership draws up the "Roadmap on Sustainability Criteria: Guidelines for Port Environmental Management", focused on methodologies, good practices and measurements assessment for the environmental sustainability of ports. This document represents the synthesis of the criteria and methodologies selection process previously conducted and is intended to globally provide directions and advice for correct use and application of improvement methods to all ports wanting to ensure a higher environmental impact of port activities and significantly improve life quality of the local populations.

The aims that MESP partnership want to follow are, specifically, to provide regulatory systems and procedures for environmental local port governing processes, offer simple and best-practice approaches to a sustainable management of harbours, especially in the air, noise and water sectors and efficient methodologies and technologies for

the environmental pollution reduction and identify suitable criteria and indicators for verifying the environmental sustainability of Mediterranean ports.

Addressed to professional figures, in scientific, operative and technical fields related to environmental pollution and scientific experts of the territory's governing and common development strategies, the report aims to provide regulatory systems and procedures for environmental local port governing processes. Moreover, it offers simple and best-practice approaches to a sustainable management of harbours and efficient methodologies and technologies for the environmental pollution reduction.

The applicability of the selected strategies has been then checked in different ports and urban realities through the realization of pilot projects (WP4). Thus, the project goals are tested as a guarantee for project proposals and have a crucial importance within the MESP project as it allows to firstly highlight the possible for any of the three thematic, a different port for demo intervention has been selected: La Spezia for air, Patras, for noise and Aqaba for water. In order to have an overall dimension of carried improvements, pilot projects on the three sectors are in phase of implementation in the Port of Tripoli [46]. This allows, once the measurement results have been collected, to evaluate if the three interventions can influence each other, improving the results or hindering other outcomes difficulties, the specific issues and the implemented adjustments.

The development of the WP4 "Pilot Projects" is articulated in different tasks. First of all, a measurement campaign to monitor and assess the actual environmental situation of pilot sites has to be carried out. Basing on the results obtained from surveys and on the provision from the "Roadmap on Sustainability Criteria: Guidelines for Port Environmental Management" document then the drawing up of the pilot projects is implemented and their realization carried on by each partner and monitored by local port authorities. As a conclusion, a second measurement campaign took place and compared with the first to evaluate and establish quantitatively the efficiency of realized interventions in the different ports. Resultantly, it indirectly validated the adequacy of the Guidelines and the standard criteria in ensuring a high environmental sustainability level in sites affected by elevated risk of pollution, such as ports and nearby urban areas.

Figure 5: The South Port or else known as New Port.

As concerns noise, the two cases represented from Patras and Tripoli ports showed two various contexts in terms of nature, extension, characterization of activities and infrastructures and integration with the urban texture. Consequentially, the approach and the assessment of the pilot project and interventions have been different as customized on the local scenario and depending on the specific noise impact on the environment.

4.1 Patras pilot project

The port of Patras is the largest and busiest marine infrastructure of Western Greece, resulting the most important at the Greek side of the Adriatic Corridor serving the Greece-Italy and Western Europe link with Ro-Ro service, for transport of freight and passengers. Today, the main function of the port is the link with the Italian ports of Brindisi, Ancona, Bari, Venezia and Trieste with ferry ships. Its Ro-Ro operations, taking place in the hinterland of Patras, serve the metropolitan Athens area, part of Western Greece, the Peloponnese and all the islands.

Patras port constitutes two separate infrastructures: the old (North) port, developed historically in close proximity with -what became later- the city centre, handling all the operations until 2010 and today serving only connections to the Ionian islands and general cargo and the new (South) port, opened for operations on July 2010 along the urban area, aimed mainly to serve the ferry route Patras-Italy (Fig. 5).

The New Port has sea side capacity of four berths and has a very high land area capacity, allowing for a much higher degree of berth utilization than the old port. Two main exits from the port area are located along the harbour borders leading, both of them, to the Patras By-Pass Highway to the directions of the city of Athens and Pyrgos. A first measurement campaign, realized to assess noise levels, allowed to identified the main noise sources within the harbour boundaries affecting the port and the surrounding area in three different activities such as the boarding

Figure 6: ADEP building, subject of intervention of MESP pilot project in Patras.

and disembarkation of passengers and vehicles, the loading, unloading and handling of containers and the use of cranes to unload all kinds of goods. Due to the increasing of urban noise levels caused by the growth and the intensification of the vehicles and, mostly, trucks to and from the port, further measurements have been realized outside the harbour, by the two exits and along the road connecting to the highway. These results showed high noise levels affecting the population living in the surrounding residential area, mostly along Eleftheriou Venizelou Street. Thus, the Patras pilot project was focused to reduce the impact on the receivers with a particular attention to noise-sensitive and highly annoyed building. Considering that the limited budget at disposal did not allow realising a significant intervention, the undertaken action in Patras foresaw the application of soundproof windows on the pilot building of ADEP S.A., directly exposed to the traffic noise in Eleftheriou Venizelou Street.

In order to protect receivers from such high noise levels and since it was impossible to act directly on the sound sources, this kind of intervention was chosen since it has been proven to be effective in other similar situations (see *e.g.* [47]) including port and maritime plant noise [48].

4.2 Tripoli pilot project

The port of Tripoli (Fig. 7), the second largest port in Lebanon, is located on the boundaries of Al-Mina and Tripoli, Lebanon, about 80 km north of the capital Beirut and about 30 km south of the Syrian borders. The port lies on 27"-34° latitude north and a 49.5"-35° longitude east, which forms a valuable geographical location on the Eastern basin of the Mediterranean Sea. In the port of Tripoli is established the "OEPT - Office of Exploitation of Port of Tripoli" which aims to manage and exploit basins, quays, warehouses and lands. Large development projects, especially the construction of a new berth (1200 m long and 15 m deep with a land area of 550000 m^2, will enhance the status of the port of Tripoli to become at par with international ports, and occupy a prominent position on the international shipping. Accordingly, the sustainability of the port area has been the concern for Port of Tripoli Authority and it includes dealing with problems that may seriously affect the environment within and outside the harbour [49].

During Tripoli pilot project activities, it has been evaluated that the daily activities of the harbour, individually and/or combined, generate a significant level of noise that impacts all workers and port employees on field. Most significant activities arose from the loading of cargo and merchandise. Traffic noise is considered a principal factor accompanying all the activities, as well as being independently a primary noise source. Along with the typical port activities generating noise, many other factors contributing to increase sound pressure level such as the behaviour of the drivers within the port area (in particular, the often-ignored speed limits, excessive honking and improper driving behaviour), the status of port roads showing unpaved parts, traffic jam mainly on quays, the age of port vehicles composed by old trucks and winches with old engines, and cargo handling on vehicles (depending on the type and quantity of cargo, the number of working winches/forklifts and the loading manner).

The implementation of a noise survey and the first monitoring campaign in the Tripoli port area identified the existing noise sources generated in the port area that cause the greatest impact. This allowed one to take actions to reduce noise pollution. Vehicles mobility and loading/discharging of cargos in the port have recorded L_{eq} average values below the national permissible limit, yet were still significant. Noise monitoring in the surrounding area was essential for the assessment of the impact of harbor activities on its environment. It was concluded that noise generated from port activities do not reach the surroundings, after monitoring in eastern and western sides [50].

This result was checked by means of the noise mapping and simulation software MITHRA SIG as shown in Figure 8.

Differently from Patras pilot project, which aimed to protect receivers from noise, Tripoli interventions involved directly the sound sources present within the harbour boundaries [46, 50].

Figure 7: Aerial view of port of Tripoli.

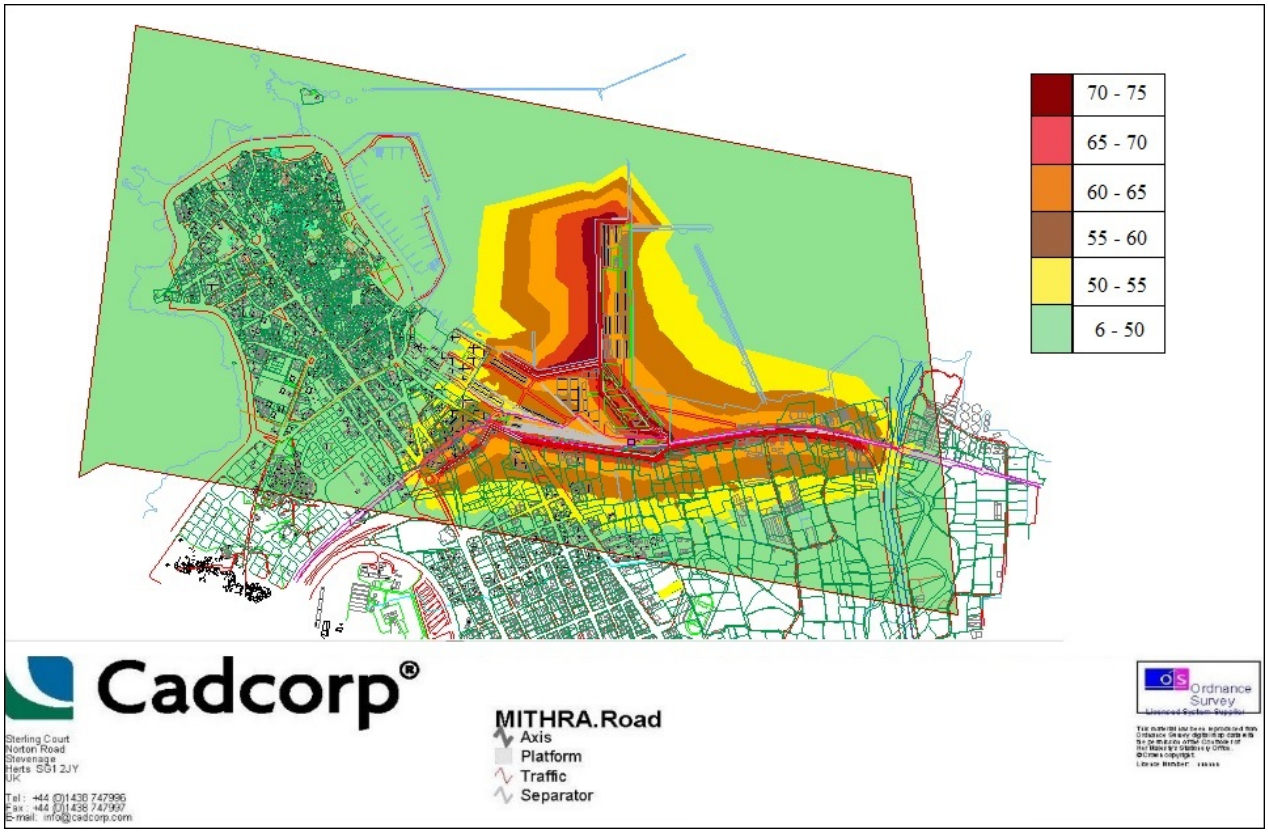

Figure 8: Noise mapping of the Port of Tripoli and the surrounding area.

The maintenance of ports equipment such as cranes, forklifts, but also trucks and vehicles resulted an important step towards reducing noise levels. In terms of traffic noise, interventions aimed to pave the road surface with sound absorbing asphalt and set direction and speed limit signs along the roads to reduce traffic and limit traffic noise.

Various mitigation actions for reducing noise levels were suggested especially along the main artery in the port. As a result of the MESP pilot project implementation, road signs conveying information on the speed limit, a ban on honking, and the presence of speed bumps and crossroads were installed. Following these interventions, a second monitoring campaign including additional testing of noise levels was held. The comparison between both monitoring campaigns showed a decrease in the average sound pressure level, and an overall decrease in the maximum levels recorded proving the efficiency of the applied mitigation actions. Nonetheless, several suggestions for interventions were recommended and will be applied in the future at the port of Tripoli, including 1) dash marking on port roads and quays, to reduce traffic and noise; 2) earplugs to be used by port workers to reduce their exposure to noise; and 3) maintenance of equipment and vehicles' engines at the port became mandated for noise reduction. Continuous monitoring of noise in the harbour area and its surroundings is recommended to ensure the sustainability of the measurement campaigns and a proper assessment of noise, especially with the development and expansion foreseen at the port of Tripoli.

5 Conclusions

Ports typically represent significant and critical areas, embracing different activities impacting both the sea and the city. In this context, the ENPI CBC MED MESP project aimed to give the opportunity for the local management authorities and port areas and infrastructures users to reach a higher level of sustainability by decreasing pollution levels, including noise. One of the main targets has been, in fact, to allow valuing and increasing the sustainability of ports through to the creation of homogeneous best practices and procedure guidelines easily applicable and reproducible in the both sides of the Mediterranean Sea. This has been possible thanks to the creation of a strong cooperation network and long-lasting collaborations among subjects of different nature such as harbour cities, port authorities and scientific skills.

Pilot project have been implemented in Patras and Tripoli to validate the selected procedures and methodologies. The two cases showed two various contexts in terms of nature, extension, characterization of activities and infrastructures and integration with the urban texture leading, in a sustainable way, to two different approaches, customized on the local scenarios and depending on the specific noise impact on the environment. From this experience general guidelines have been drawn up, so that a general fallout was obtained and an operative support was given to adopt strategies and solutions to face port noise in an early stage, avoiding subsequent expensive recovery actions.

During the activity, all partners shared knowledge progress and cooperated aiming to jointly capitalize the results achieved by this project financed under ENPI CBC MED Programme 2007–2013. The target was to disseminate the project outcome and capitalize the experience concerning the topic addressed, in view of identifying good practices and common valuable approaches. For this purpose, complementarities and synergies of the results among the other ENPI CBC MED projects have been highlighted.

Continuous dissemination activities are continuously undertaken through the participation of MESP partners to public events, meetings and congress and the connection to European projects on similar topics. This allows for the transmission of MESP target goals and results, raising awareness among citizens, local authorities, and stakeholders on noise pollution abatement in ports.

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